

# Unveiling Vela - Time Variability of Interstellar Lines in the Direction of the Vela Supernova Remnant II. Na D and Ca II <sup>\*</sup>

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## ABSTRACT

In a survey conducted between 2011-12 of interstellar Na I D line profiles in the direction of the Vela supernova remnant, a few lines of sight showed dramatic changes in low velocity absorption components with respect to profiles from 1993-1994 reported by Cha & Sembach. Three stars - HD 63578, HD 68217 and HD 76161 showed large decrease in strength over the 1993-2012 interval. HD 68217 and HD 76161 are associated with the Vela SNR whereas HD 63578 is associated with  $\gamma^2$  Velorum wind bubble. Here, we present high spectral resolution observations of Ca II K lines obtained with the Southern African Large Telescope (SALT) towards these three stars along with simultaneous observations of Na I D lines. These new spectra confirm that the Na D interstellar absorption weakened drastically between 1993-1994 and 2011-2012 but show for the first time that the Ca II K line is unchanged between 1993-1994 and 2015. This remarkable contrast between the behaviour of Na D and Ca II K line absorption lines is a puzzle concerning gas presumably affected by the outflow from the SNR and the wind from  $\gamma^2$  Velorum.

**Key words:** Star: individual: ISM: variable ISM lines: Supernova Remnants :other

## 1 INTRODUCTION

Vela supernova remnant (SNR) is the closest relic of a stellar explosion to earth, located at a distance of  $287 \pm 19$  pc, as inferred from the VLBI parallax of its pulsar (Dodson et al 2003) and represents a supernova explosion that occurred 11000 years ago (Reichley, Downs & Morris 1970). Observational studies of interstellar lines present in the spectra of stars in the direction of Vela SNR provide information about the interaction of the remnant with local interstellar medium (ISM). Such studies predominantly concentrated on

profiles of Ca II K and Na I D lines superimposed on stellar spectra.

Recently, we completed a study of high resolution Na I D line profiles towards sixty four OB stars in the direction of Vela SNR, mainly carried out during 2011-2012, and compared them with Ca II K and Na I D line profiles of the same stars earlier obtained by Cha & Sembach (2000) in the period 1993-1996 at comparable spectral resolution (Rao et al 2015 -hereafter Paper I). Comparison of the profiles of Na I D from these two epochs revealed major decreases in low velocity absorption components towards a few stars. When Paper I was written, we did not have Ca II K profiles for comparison with K line observations of Cha & Sembach (2000) to constrain the cause of this Na D variability. Subsequently, we could obtain with the high-resolution spectrograph at Southern African Large Telescope (SALT) Ca II K profiles for three of the stars exhibiting dramatic weakening of Na D absorption. In the present paper, we report on the Ca II K

<sup>\*</sup> Based on observations obtained with Southern African Large Telescope (SALT) and The Vainu Bappu Telescope (VBT).

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and Na I D lines towards three stars in which D line absorption at low velocities weakened greatly between 1993-1994 and 2011-2012. The surprising result is that in sharp contrast to the Na D lines the Ca II K line in 2015 has the same profile in all three cases as it did in 1993-1994.

Earlier studies of interstellar absorption lines towards various stars in and around the Vela SNR indicated that high velocity (i.e.  $> 100 \text{ km s}^{-1}$ ) components, most commonly seen in Ca II profiles, manifest shocked gas associated with the SNR (Wallerstein, Silk & Jenkins 1980; Jenkins, Wallerstein & Silk 1984). Sushch, Hnatyk & Neronov (2011) pointed out that only stars with distances greater than 500 pc show these high-velocity components in their spectrum (see Paper I figure 18, Cha, Sembach & Danks 1999). For reference, the pulsar is at about 290 pc and the three stars of interest here are at 300-500 pc and do not show high-velocity interstellar components. The diameter of Vela supernova remnant is estimated to be about 8.3 degrees (Aschenbach 1993; Aschenbach, Egger & Trumper 1995). Two of the three stars discussed here, HD 68217 and HD 76161, are located in the outer edge of the ROSAT X-ray image of the SNR. The third one, HD 63758, is located in the  $\gamma^2$  Vel wind bubble region.

## 2 OBSERVATIONS

Our high-resolution spectra of the three stars discussed here were obtained at two observatories. The resolving power  $R = \lambda/d\lambda$  of the spectra is comparable to that of the baseline spectra by Cha & Sembach (2000) who reported a value of  $R = \lambda/d\lambda \simeq 75000$ .

Observations of the Na D lines in Paper I

have been obtained with a 45 meter fiber-fed cross-dispersed echelle spectrometer at the 2.3 meter Vainu Bappu Telescope (VBT) at the Vainu Bappu Observatory (Rao et al. 2005).  $R = \lambda/d\lambda$ , the spectral resolving power with a  $60 \mu\text{m}$  m slit, was 72000. The spectrum covers the wavelength range of 4000 to 10000 Å with gaps. Beyond about 5600 Å the echelle orders were incompletely recorded on a E2V 2048×4096 CCD chip. Although Na D lines are captured, the Ca II H & K lines occur in the insensitive region. The wavelength calibration was done using Th-Ar hollow cathode lamp exposures that were obtained soon after the exposures on the star.

New high resolution spectra of Ca II H & K lines along with Na I D lines have been acquired with the high resolution spectrograph (HRS) on the Southern African Large Telescope (SALT) on 2015 December 15 (Bramall et al. 2010). The HRS blue spectrum with a 1.6 arc sec fiber provides a resolving power of 66700. Spectra with Both blue arm (3674-5490 Å) and red arm (5490-8810 Å) have been obtained. The S/N ratio of the red spectrum in the region of the Na D lines is comparable to that of the VBT spectra  $\sim 80 - 100$  and the spectra obtained by Cha & Sembach (2000). However, the SALT spectra around the Ca II K line are of a lower S/N ratio ( $\sim 35 - 50$ ) than the spectra provided by Cha & Sembach (2000). The resolving power of the SALT spectra is 63000 at the D lines as measured from the width of weak telluric lines and comparable at K line.

IRAF routines have been used for spectral reductions namely flat field corrections, bias subtractions, wavelength

calibration and corrections for telluric line blending. We adopted the same local standard of rest (LSR) of Cha & Sembach (2000) for converting heliocentric velocities to LSR velocities. Decomposition of various components from the observed line profiles are accomplished by fitting Gaussian profiles. Central radial velocity  $V_{\text{LSR}}$ , full width at half maximum and equivalent width of the components have thus been obtained from these fits. The values of these parameters listed in Cha & Sembach (2000) were used as starting values for the gaussian fits and further changes were made so as to make both  $D_2$  and  $D_1$  profiles yield the same number of components, same  $V_{\text{LSR}}$  and also similar full width at half maximum. The combined gaussian fits are made to match the observed profiles such that no residuals are left over the noise in the surrounding continuum. These fits are of doubtful validity when the lines are saturated, as is the case for some Na D profiles. When multiple observations are available an average equivalent width of the components is presented in tables. The SALT spectra in the D line region are not corrected for telluric line contamination, since simultaneous telluric line standard star observations were not obtained. As a result radial velocity and equivalent width of few  $D_2$  components are affected by telluric lines. However,  $D_1$  profiles are fine. The LSR radial velocities of the Na I D line components obtained from SALT profiles agree with in  $\pm 2 \text{ km s}^{-1}$  with the ones measured from VBT profiles.

## 3 SIGHT LINES TOWARDS WHICH LARGE VARIATIONS OF NA I COLUMN DENSITY HAVE BEEN OBSERVED

Low  $V_{\text{LSR}}$  velocity clouds that are recognised through Na D and Ca II absorption components are usually considered to be associated with diffuse interstellar medium in the spiral arms. However interstellar clouds in the proximity of the Vela supernova remnant might have experienced interactions with the remnant through radiation or collisions and thus, their physical conditions and kinematics altered.

Our survey of interstellar Na D lines (Paper I) showed that the most of the stars observed with VBT during 2011-12 had their Na D profiles unchanged compared to 1993-1996 observations of Cha & Sembach (2000). Most of the low velocity components, generally in the  $V_{\text{LSR}}$  range of  $\pm 25$  to  $0 \text{ km s}^{-1}$  (Cha, Sembach & Danks 1999) of Na D absorption might have their origins in clouds that occur in the intervening spiral arms. A remarkable result of Paper I was a great decrease in strength (almost disappearance) of low-velocity absorption components in Na D lines in just three stars – HD 63578, HD 68217 and HD 76161, in the period between 1993 – 1996 and 2011 – 2012. This trio is discussed here in light of the SALT spectra of both Na D and the Ca K lines. Two simple questions may be addressed with the acquisition of the SALT spectra: (i) Do the 2015 SALT Ca II K line profiles differ from those that were obtained by Cha & Sembach during 1993-1994, in a similar way to the large changes seen in the Na D profiles between 1993-1994 and 2011-2012? and (ii) Have the Na D profiles evolved further in the interval three-four year between the VBT and SALT observations? (Cha & Sembach noticed changes in strength and velocity in some high velocity absorption components in their observing period of about three years, but our VBT spectra

**Table 1.** Absorption Lines of Ca II K & Na I towards HD 63578

Ca II K			Na I C & S <sup>a</sup>			Na I (VBT) <sup>b</sup>			Na I (SALT) <sup>c</sup>	
C&S		SALT	<i>D</i> <sub>2</sub>		<i>D</i> <sub>1</sub>	<i>D</i> <sub>2</sub>		<i>D</i> <sub>1</sub>	<i>D</i> <sub>2</sub>	<i>D</i> <sub>1</sub>
<i>V</i> <sub>LSR</sub> km s <sup>-1</sup>	Eq.w (mÅ)	Eq.w (mÅ)	<i>V</i> <sub>LSR</sub> km s <sup>-1</sup>	Eq.w (mÅ)	Eq.w (mÅ)	<i>V</i> <sub>LSR</sub> km s <sup>-1</sup>	Eq.w (mÅ)	Eq.w (mÅ)	Eq.w (mÅ)	Eq.w (mÅ)
-14	24	28				-13	31	15	(27)	14
			-4	223	178	-6	39	24	*	21
6	34	43				6	232	191	230	191
			11	325	270					
						22	5			

<sup>a</sup> C&S: Cha & Sembach (2000) observations from 1993<sup>b</sup> VBT: Average of four nights from 2011- 2012 (see Paper I)<sup>c</sup> SALT: Observation from 2015 December 15

\* : Affected by telluric line

**Table 2.** Absorption Lines of Ca II K & Na I towards HD 68217.

Ca II K			Na I (C & S) <sup>a</sup>			Na I (VBT) <sup>b</sup>			Na I (SALT) <sup>c</sup>	
C&S		SALT	<i>D</i> <sub>2</sub>		<i>D</i> <sub>1</sub>	<i>D</i> <sub>2</sub>		<i>D</i> <sub>1</sub>	<i>D</i> <sub>2</sub>	<i>D</i> <sub>1</sub>
<i>V</i> <sub>LSR</sub> km s <sup>-1</sup>	Eq.w (mÅ)	Eq.w (mÅ)	<i>V</i> <sub>LSR</sub> km s <sup>-1</sup>	Eq.w (mÅ)	Eq.w (mÅ)	<i>V</i> <sub>LSR</sub> km s <sup>-1</sup>	Eq.w (mÅ)	Eq.w (mÅ)	Eq.w (mÅ)	Eq.w (mÅ)
			-18	17	≤ 6	-19	9	5	*	3
-8.0	14	15	-8	30	20	-8	10	5	*	3
			2	43	12	2	41	22	41	17
9.0	20	25	9	20	16	9	21	10	21	9

<sup>a</sup> C&S: Cha & Sembach (2000) observations from 1994<sup>b</sup> VBT: Average of four nights from 2011- 2012 (see Paper I)<sup>c</sup> SALT: Observation from 2015 December 15

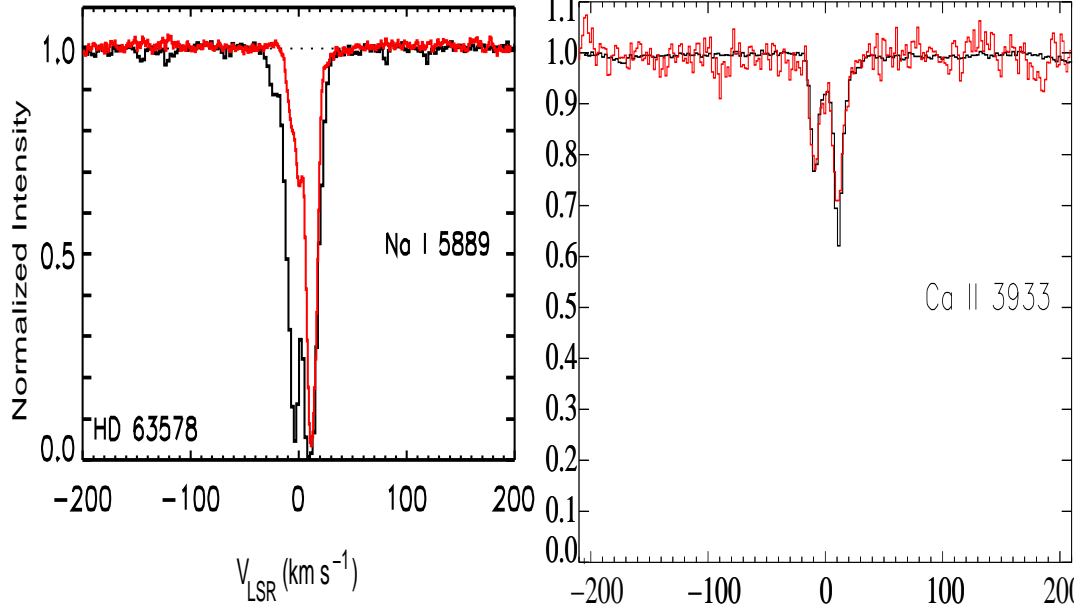
\* Affected by telluric line

**Table 3.** Absorption Lines of Ca II K and Na I towards HD 76161

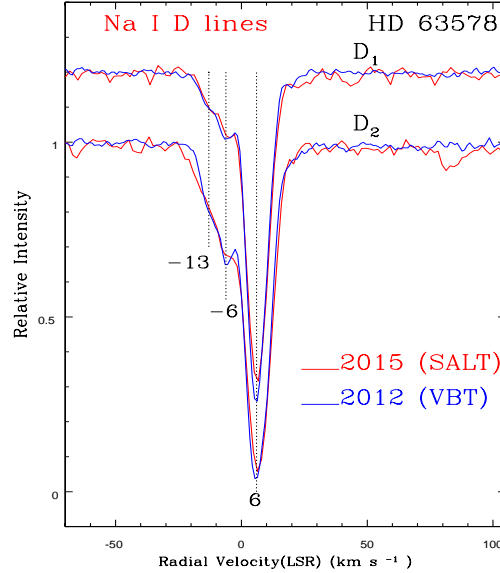
Ca II K			Na I (C & S) <sup>a</sup>			Na I (VBT) <sup>b</sup>			Na I (SALT) <sup>c</sup>	
C&S		SALT	<i>D</i> <sub>2</sub>		<i>D</i> <sub>1</sub>	<i>D</i> <sub>2</sub>		<i>D</i> <sub>1</sub>	<i>D</i> <sub>2</sub>	<i>D</i> <sub>1</sub>
<i>V</i> <sub>LSR</sub> km s <sup>-1</sup>	Eq.w (mÅ)	Eq.w (mÅ)	<i>V</i> <sub>LSR</sub> km s <sup>-1</sup>	Eq.w (mÅ)	Eq.w (mÅ)	<i>V</i> <sub>LSR</sub> km s <sup>-1</sup>	Eq.w (mÅ)	Eq.w (mÅ)	Eq.w (mÅ)	Eq.w (mÅ)
-8	16	6	-6	94	32	-9	6	3	*	4
2	38	43				2	60	32	63	28
			9	395	365					
						13	8	4	10	6
			27	61	32					

<sup>a</sup> C&S: Cha & Sembach (2000) observations from 1993<sup>b</sup> VBT: Average of four nights from 2011- 2012 (see Paper I)<sup>c</sup> SALT: Observation from 2015 December 15

\* Affected by telluric line



**Figure 1.** (Left): Profile of Na I D<sub>2</sub> in HD 63578 obtained in 2011 (red line) shown superposed on the profile of Na I D<sub>2</sub> observed in 1993 by Cha & Sembach (2000) (black line). The blue-shifted absorption components in the 1993 spectrum (black line) is absent in the 2011 spectrum. (Right): Ca II K profiles of HD 63578 obtained with SALT in 2015 (red line) overplotted on profile obtained by Cha & Sembach (2000) in 1993.



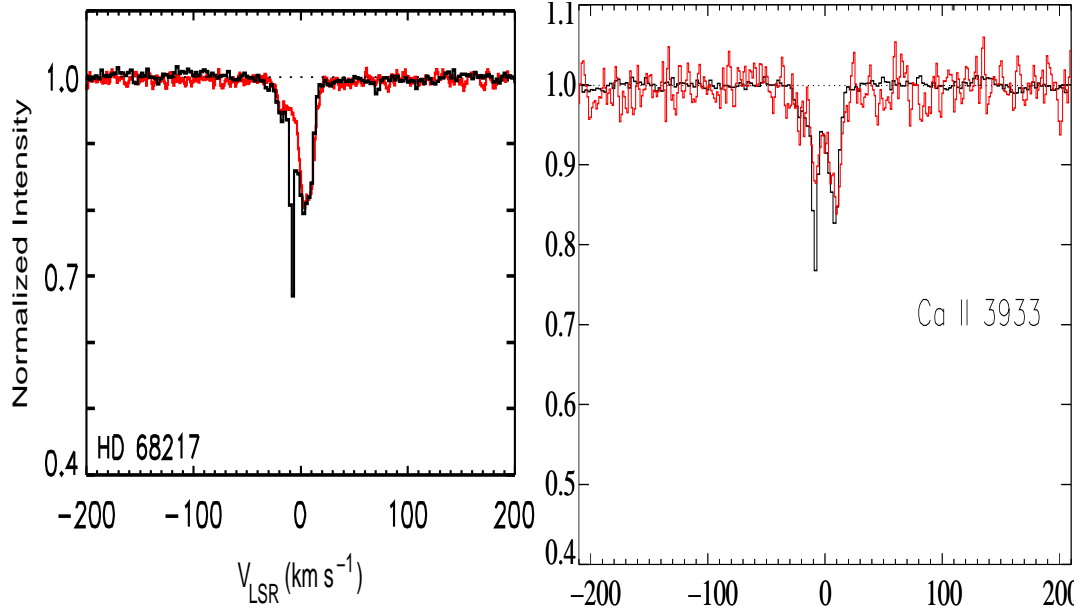
**Figure 2.** The profiles of Na I D in HD 63578 obtained during 2012 (blue line) are superposed with profiles obtained in 2015 with the SALT (red line). The SALT spectrum was not corrected for (weak) telluric lines. The dotted lines show the velocities of the four Gaussian components fitted to the profiles – see Table 1.

have a limited information on such absorption components. In particular, the three stars observed at SALT have not shown high velocity components in any available spectra. High-velocity components appeared more frequently in the Ca II K line than the Na I lines.)

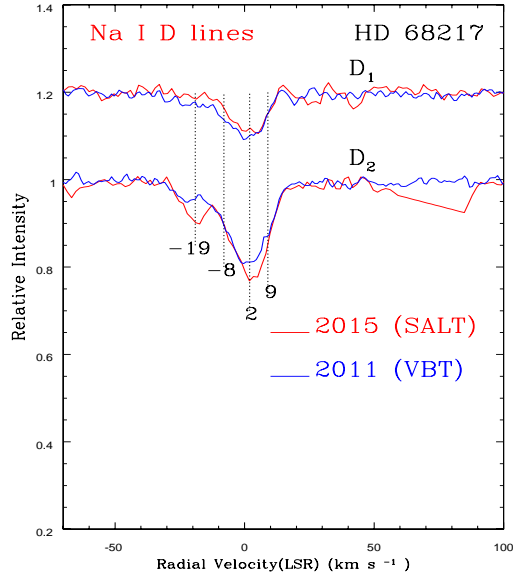
**HD 63578:** For this star located at a distance of 150 pc behind  $\gamma^2$  Velorum and seemingly in the bubble generated by  $\gamma^2$  Velorum’s wind ( see Paper I ), Figure 1(left) shows the much weaker low velocity Na D<sub>2</sub> line in 2011 relative to

that in 1993. The figure also shows that the D<sub>2</sub> profile did not change further between 2011 and 2015 (Figure 2) . In striking contrast, the Ca K line’s are unchanged between 1993 and 2015 (Figure 1-right).

Gaussian components extracted from the spectra are summarized in Table 1. These show that the Ca K line’s two components are unchanged in velocity and equivalent width between 1993 and 2015 except perhaps for a possible increase in the redder component in the SALT spectrum.



**Figure 3.** (Left panel): Profile of Na I D<sub>2</sub> in the sight line to HD 68217 as obtained in 1994 by Cha & Sembach (black line) superposed on the D<sub>2</sub> profile obtained on 2012 January 16 with the VBT (red line). The strong absorption component present at  $V_{\text{LSR}} = -9 \text{ km s}^{-1}$  in 1994 is conspicuously weakened by 2012. (Right panel): The Ca II K profile obtained with SALT in 2015 of HD 68217 (red line) is overplotted on the profile obtained in 1994 by Cha & Sembach (2000) (black line). There may be a slight weakening of the sharp absorption component at  $-8 \text{ km s}^{-1}$  by the time the SALT profile was obtained.



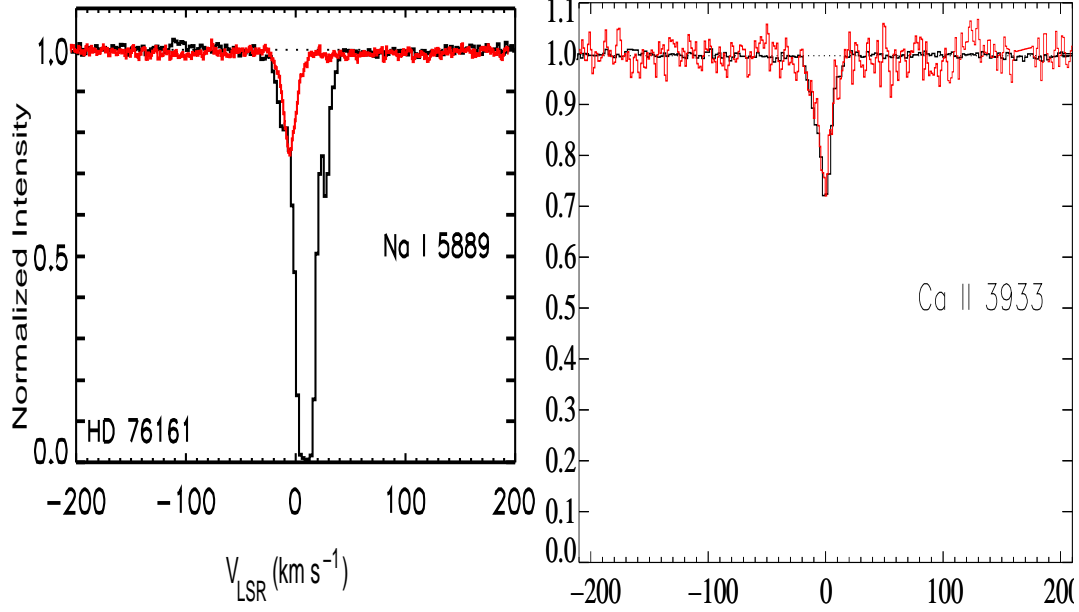
**Figure 4.** Profiles of Na I D<sub>2</sub> and D<sub>1</sub> obtained with VBT in 2011 (blue lines) are compared with profiles obtained on 2015 December 25 with SALT (red line). The profiles are very similar indicating no significant change occurred between 2011 and 2015. The SALT spectrum was not corrected for (weak) telluric lines. The dotted lines show the velocities of the Gaussian components fitted to the Na D profiles – see Table 2.

Cha & Sembach note that the two velocity components are traceable back to 1971 - 1977.

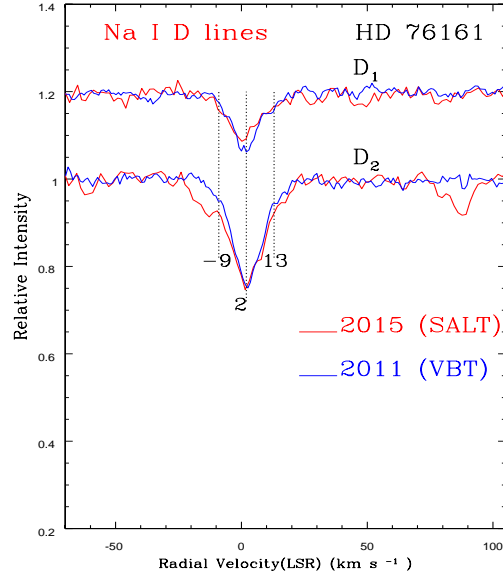
At Na D, Cha & Sembach fitted their 1993 spectrum with strong components (Table 1) at  $-4$  and  $+11 \text{ km s}^{-1}$  which differ by several  $\text{km s}^{-1}$  from their velocities of  $-14$  and  $+6 \text{ km s}^{-1}$  obtained from the much weaker Ca K line. For the VBT and SALT Na D lines, there are components

at  $-13$  and  $+6 \text{ km s}^{-1}$  apparently coincident with the Ca K components plus another weak Na D component at  $-6 \text{ km s}^{-1}$ .

Jenkins, Wallerstein & Silk (1984) obtained an ultra-violet spectrum of the star with the IUE on 1979 June 15. They measured for both C I, Si II, and Si II-Fe II lines LSR radial velocities of  $+9$ ,  $+7$  and  $+2 \text{ km s}^{-1}$ , respectively. The



**Figure 5.** (Left panel): Profiles of Na I D<sub>2</sub> in the sight line towards HD 76161 obtained with VBT on 2011 December 25 (red line) is superposed on the 1993 profile obtained by Cha & Sembach (2000) (black line). Strong absorption components at  $V_{\text{LSR}} = 9$  and  $27 \text{ km s}^{-1}$  have almost disappeared by the time of VBT observations in 2011. (Right panel): Ca II K profiles of HD 76161 obtained with SALT in 2015 (red line) overplotted on 1993 profile obtained earlier by Cha & Sembach (2000).



**Figure 6.** Na I D<sub>2</sub> and D<sub>1</sub> profiles obtained in 2011 with (blue lines) VBT are compared with profiles obtained on 2015 Dec 15 with SALT (red line). The profiles are very similar indicating no significant change occurred between 2012 and 2015. The SALT spectrum was not corrected for telluric lines. The dotted lines show the velocities of the Gaussian components fitted to the Na D lines – see Table 3.

$+9 \text{ km s}^{-1}$  velocity is coincident with the  $+9 \text{ km s}^{-1}$  component of Ca K. The  $-4 \text{ km s}^{-1}$  component that has been present in 1993 spectrum in Na D lines was not seen in either C I or in singly ionized lines of Ca, S, Si and Fe. Thus, this component probably refers to a cold gas cloud seen only in Na D.

**HD 68217:** This star lies near the edge of the ROSAT image of the Vela SNR. Figure 3(left) shows that a sharp Na D component at  $-8 \text{ km s}^{-1}$  almost vanished by 2011-2012

but remained without additional change in 2015 (Figure 4). Table 2 shows that the Gaussian components for the Ca K line have close counterparts in the Na D profiles and, in particular, the sharp feature at  $-8 \text{ km s}^{-1}$  which weakened greatly at Na D may also have weakened at Ca K (Figure 3-right). The four Na D components identified by Cha & Sembach are present in the VBT and SALT spectra with the  $-8 \text{ km s}^{-1}$  feature weaker in the latter spectra. A Na D spectrum obtained in 1989 by Franco (2012) with the

same instrument used by Cha & Sembach shows the  $-8 \text{ km s}^{-1}$  feature weaker than it was in 1994 but stronger than in VBT and SALT spectra which suggests that the feature's evolution is not a simple one.

**HD 76161:** This star which like HD 68217 lies near the edge of the ROSAT image of the Vela SNR (paper I) provides the third and the extreme example in which low velocity strong Na D absorptions present in 1993 had almost disappeared by 2011 - see Figure 5(left) : the saturated absorption component at  $V_{\text{LSR}} + 9 \text{ km s}^{-1}$  has vanished almost completely by 2011. A redward weaker absorption component at  $+27 \text{ km s}^{-1}$  present in 1993 also weakened drastically by 2012. However a weak absorption component at about  $-9 \text{ km s}^{-1}$  seems unchanged over the period of 1993 to 2012 baseline. The Na D profile remained unchanged in the period 2011 to 2015 (Figure 6).

The 1993 Ca II K profiles of 1993 and 2015 (Figure 5-right) appear with components at  $-8$  and  $+2 \text{ km s}^{-1}$  (Table 3). The Ca II K profile obtained between 1971-77 period by Wallerstein, Silk & Jenkins (1980) appears to be similar to the profile observed by Cha & Sembach (2000) in 1993.

Jenkins, Wallerstein & Silk (1984) measured LSR radial velocity of Si II and Si II + Fe II as  $-3 \text{ km s}^{-1}$  and  $-7 \text{ km s}^{-1}$  respectively from their IUE spectrum obtained in 1979 September 26, very similar values to that of Ca II K components measured by Cha & Sembach (2000) in 1993.

Later, Nichols & Slavin (2004) detected C I lines at the LSR velocity of  $8 \text{ km s}^{-1}$  in the same IUE spectrum obtained in 1979. This velocity corresponds to the strong Na I component that disappeared after 1993. It appears that a strong neutral cloud was present at  $+9 \text{ km s}^{-1}$  for at least a period of 14 years prior to 1993 and then vanished some time in the next 18 years.

Nichols & Slavin (2004) investigated C I lines in 54 stars in Vela SNR region including HD 76161, and noted the redshift of C I lines with respect to ionized lines and suggested that C I lines from the ground-state of the atom are a combination of two absorption components: one near zero velocity which might have its origins in the clouds in the spiral arm along the sight lines to the star and the other component at a higher velocity arising from cloud that might have interacted with the Vela SNR. They also suggest that redshift observed in C I ground-state lines might have its origins in a H I shell on the back side of the remnant. Dubner et al. (1998) discovered a shell of H I through 21 cm emission around Vela SNR that follows closely the ROSAT's outer X-ray bright shell. This  $30 \text{ km s}^{-1}$  expanding The H I shell is thought to be a result of recombined postshocked gas behind the advancing shock front. There is the possibility that the cold neutral cloud that disappeared in the direction of HD 76161 might have been a shocked cloud.

#### 4 CONCLUDING REMARKS

The focus of the paper has been three stars in the direction of the Vela SNR in which a severe weakening of low-velocity absorption components of interstellar Na D lines occurred between 1993-1994 and 2011-2012 (Rao et al. 2016). Such low-velocity components are assumed to belong to the local interstellar medium and not to be an immediate product of the Vela SNR or other energetic sources in the vicinity of

the Vela nebula. A few earlier reports for stars behind the Vela SNR have noted modest variations in the Na D lines at low velocity - see, for example, observations of the visual binary HD 72127 (Hobbs, Wallerstein & Hu 1982; Hobbs et al. 1991; Welty, Simon & Hobbs 2008). The magnitude of the weakening reported by us earlier is unprecedented in published studies of interstellar Na D lines (see, for example, McEvoy et al. 2015) and is plausibly attributable to interactions between ambient diffuse interstellar gas and the high-velocity gas in and around the Vela nebula from the Vela supernova and the winds from massive stars. It seems highly pertinent to note that out of forty one stars with Na D lines observed previously by Cha & Sembach and again at the VBT none showed a comparable strengthening of the Na D lines between 1993-1994 and 2011-2012. (As noted for HD 68217, A low-velocity component Na D did strengthen between 1998 and 1994. Also, HD 73882, a star behind the Vela SNR showed a strengthening of the Ca I 4226 Å line between 2006 and 2012 (Galazutdinov et al. 2013) and presumably the Na D lines also strengthened over this interval.)

The better established signature of these interactions between high-velocity gas and the ambient interstellar medium is the presence of high-velocity ( $|V_{\text{LSR}} \sim 100| \text{ km s}^{-1}$ ) absorption components seen in stars with distances greater than about 500 pc. High-velocity gas was first reported by Wallerstein & Silk (1971) and Thackeray & Warren (1972) from observations of the Ca II K line with extensive follow-up at the Ca II K line and Na D lines by Cha & Sembach (2000). (High-velocity Na D gas associated with the SNR Monoceros Loop has been shown to be variable (Dirks & Meyer 2016).) High-velocity gas associated with Vela has been studied in the ultraviolet (Jenkins, Wallerstein & Silk 1976; Wallerstein, Silk & Jenkins 1980; Jenkins et al. 1981; Jenkins, Wallerstein & Silk 1984). With respect to the Na D and Ca K line, a characteristic of the high-velocity gas is the several 100-fold increase with respect to the value for low velocity gas of the column density ratio of Ca II to Na I which is attributed to the destruction of interstellar grains and release of substantial amounts of Ca (and other elements) but not Na which is little depleted by grains (Spitzer 1978; Danks & Sembach 1995; Sembach & Danks 1994).

Surely, the outstanding characteristic of the low-velocity interstellar lines of the three sightlines where the Na D lines are strikingly weakened between 1993-1994 and 2012-2015 is that the Ca K line shows no detectable change between 1993-1994 and 2015 in two cases (HD 63578 and HD 76161) and a possible mild weakening in the third case (HD 68217) where the central depth of the component coincident in velocity with the varying Na D feature drops from 77% in 1994 to 88% in 2015, a drop only slightly larger than the amplitude of the noise in the SALT spectrum. In short, the Ca K line is effectively unaffected by the factors responsible for the large Na D changes and, in particular, the Ca K's velocity component coincident with the variable Na D component are unaffected. This contrast between Na D and Ca K constrains the factors driving the weakening of the Na D line.

Estimation of the Na I column density for two of the three examples is an uncertain procedure for the 1993-1994 spectra because the dominant components are saturated. For the VBT and SALT spectra, the variable component of

the Na D lines is little saturated; the equivalent widths of the D<sub>2</sub> and D<sub>1</sub> lines approach the 2:1 weak line limit. For HD 68217, the  $-8 \text{ km s}^{-1}$  component appears to provide both the Na D and Ca K line and assuming that the lines are unsaturated, the column density ratio  $N(\text{Ca II})/N(\text{Na I})$  was about 3 in 1994 and increased to 17 in 2015. For the other two stars, the ratio  $N(\text{Ca II})/N(\text{Na I})$  for the highly-variable component was between about two and four in 2015. The 1993-1994 ratios were obviously much smaller because of the larger Na I column densities and these ratios appear typical of diffuse clouds (Danks & Sembach 1995). The ratio of 17 for HD 68217 in 2017 is typical of values for high-velocity clouds in the Vela SNR (Sembach & Danks 1994) but the change between 1993-1994 and 2015 seems unlikely to be due to release of Ca from grains because the Ca K line's equivalent width is unchanged over this interval and the increase in the ratio arises from loss of neutral Na presumably to ionization. High-velocity clouds moving tangentially to the line of sight may appear as low velocity clouds and this likelihood is increased for stars such as our trio located near the edge of the SNR.

Interactions between the SNR and an ambient diffuse diffuse cloud may break the cloud into smaller parts. Pakhomov, Chugai & Iyudon (2012 – see also Klein, McKee & Colella 1994) discuss how a fast-moving shock interacts with a diffuse cloud. Three stages of interaction are envisaged. First, the shock propagates through the cloud. In the second stage, the cloud is accelerated. Finally, the cloud is fragmented. It seems that the interaction can destroy a small (diameter of a few au) cloud in a few years. Although detailed calculations remain to be done to show that almost complete disappearance of Na D lines may be achieved with almost no change of the Ca K line, it seems, as the referee has pointed out, unlikely that large-scale fragmentation can lead to a large Na D reduction without a change in Ca K and, moreover, changes in radial velocity are likely to accompany column density changes.

Nonetheless, the fact that these remarkable changes in Na D lines unaccompanied by Ca K line changes occur on sight lines to SNR or through a region crossed by a vigorous stellar wind and have not been seen sight lines through the ambient diffuse stellar medium suggests that shocks may be the key to understanding our remarkable discovery. Shock fronts even at low velocities can emit Ly-alpha photons (Shull & McKee 1979). Lyman  $\alpha$  at 10.2 eV can ionize neutral Na with its ionization potential of 5.14 eV but not Ca<sup>+</sup> with its ionization potential of 11.9 eV. As the front approaches the cloud, the increase in Lyman  $\alpha$  flux could be rather abrupt; the zone containing Lyman  $\alpha$  photons ahead of the front can be narrow because Lyman  $\alpha$  photons scatter many times in a neutral hydrogen medium. (This appealing argument we owe to the referee.)

A strictly geometrical explanation but perhaps overlooking the SNR and stellar wind association may be possible. The column density ratio of Na D/Ca K for diffuse clouds spans the range from 300 to 0.02 (Welty, Morton & Hobbs 1996). If a thin cloud of high Na D/Ca K moved out of the line of sight to our three stars, the Na D line would weaken sharply but, perhaps, the Ca K line would be largely unchanged. Observations of sight lines through the general interstellar medium do not support this idea as a common event as we find towards the Vela SNR.

The principal next challenge suggested by our VBT and SALT spectroscopy of Na D and Ca K lines is to catch and follow large scale changes occurring along a line of sight. Panoramic optical spectroscopy will be able to observe the behaviour of many interstellar lines (see, for example, Pakhomov, Chugai & Iyudin 2012). Since there is as yet no predictor of which star is about to undergo a change in its interstellar lines, detection of an onset will require routine high-resolution monitoring of a set of stars in and around the Vela SNR but this presents a severe scheduling challenge and involves a considerable consumption of observing time. Although observation of transient phenomena is a 'hot' contemporary topic, its remit does not yet extend to exploration of the questions raised by our paper.

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